EOLIAN LANDFORMS OF ALBERTA

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EOLIAN LANDFORMS OF ALBERTA

by

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ABSTRACT

Proper evaluation and assessment of eolian landform types helps in the identification of areas which represent a diversity of natural features within a particular region. Although the presence of extensive sand dunes in Alberta has been known for some time, there has been very little systematic work done in the past on mapping, identification and evaluation of the various eolian landform types. The objective of this report is to bridge this gap.

A majority of the sand grains that form sand dunes are believed to have been reduced to their present sizes by the action of water, wind, heat and ice. The sheer stress at the sand surface due to wind is one of the significant factors that determine the magnitude of eolian transport.

The sand transporting capacity of the wind is chiefly dependent upon the velocity of the wind. Consequently, powerful winds of short duration are believed to be more effective than gentle winds of long duration.

The main source materials for the sands in the major sand dune areas in Alberta are glaciolacustrine and fluvial deposits. On the basis of the available information, the prevailing winds were mainly northwesterly for the dunes in northern and central Alberta, and southwesterly in the southern parts of the province.

Four principal dune forms exist in Alberta: erosional, individual, composite and dune ridge. The largest and best represented are the individual dune forms, with the parabolic dune type being the most widespread. The U-shaped and V-shaped dune types rank a close second while fish hook and harpoon dune types are the least common. The transverse, longitudinal and barchan dunes (desert dunes) are poorly represented in Alberta.

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PREFACE

This project was initiated in 1981 as a part of the program by the Renewable Resource Inventory Section, Resource Evaluation Branch, to meet the needs and requirements of resource planning and management agencies within the department and other interested government and research groups.

The purpose of this report is to provide data on the characteristics, location and distribution of the eolian landform features. Throughout the report special emphasis is placed on the qualitative assessment of the diversity and uniqueness of the eolian features mapped.

The report provides background information on the source materials and the effective winds that were the force behind the movement and deposition of the sand.

In the report, P. David's classification of the eolian landforms has been used and each category described in detail. A general map at a scale of 1:1 500 000 showing the distribution of the eolian landforms accompanies the report.

It must be realized that the basic purpose of this study is to provide information for broad or regional levels of resource planning and management. For detailed on-site planning and management, on-site examination is necessary.

ACKNOWLEDGEMENTS

This project was funded jointly by the Resource Evaluation Branch and the Land Management and Development Branch of the Alberta Department of Forestry, Lands and Wildlife.

In compiling information contained in this report the author has had to rely heavily on the support and help of members of staff of both branches. E. Karpuk has been involved in this project since its inception. His leadership role during the mapping stage is gratefully acknowledged.

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this study was to assess and evaluate all existing eolian landforms in the province of Alberta. More specifically, the report entails: (a) mapping of all eolian landform features that occur throughout Alberta and covering 10 km^2 or more in areal extent; (b) an assessment and description of the features mapped; and (c) qualitative assessment of the diversity, uniqueness and extent of eolian features. In many parts eolian landforms constitute unique features in the varied landscape of Alberta. Throughout the report emphasis has been placed on the identification and qualitative assessment of the sites where the sand dune features are best represented.

1.2 Previous Work

In comparison with the extensive amount of work that has been carried out in other areas of geology and geomorphology, the study of eolian deposits in Alberta has received, at most, a cursory treatment. Limited studies specifically devoted to eolian landform features have been undertaken (Odynsky 1958). Mention has been made in various reports regarding the occurrence of sand dunes in Alberta (Westgate 1965; Jones 1966; Odynsky and Lindsay 1957-1958; Gravenor and Ellenwood 1957; Torkarsky 1977; Barnes 1977; Davis 1977).

Odynsky (1958) conducted an analysis of the U-shaped dunes and effective wind directions in Alberta. His investigations can appropriately be described as a pioneer study of the U-shaped dunes in Alberta despite the fact that his report was published in an abridged form.

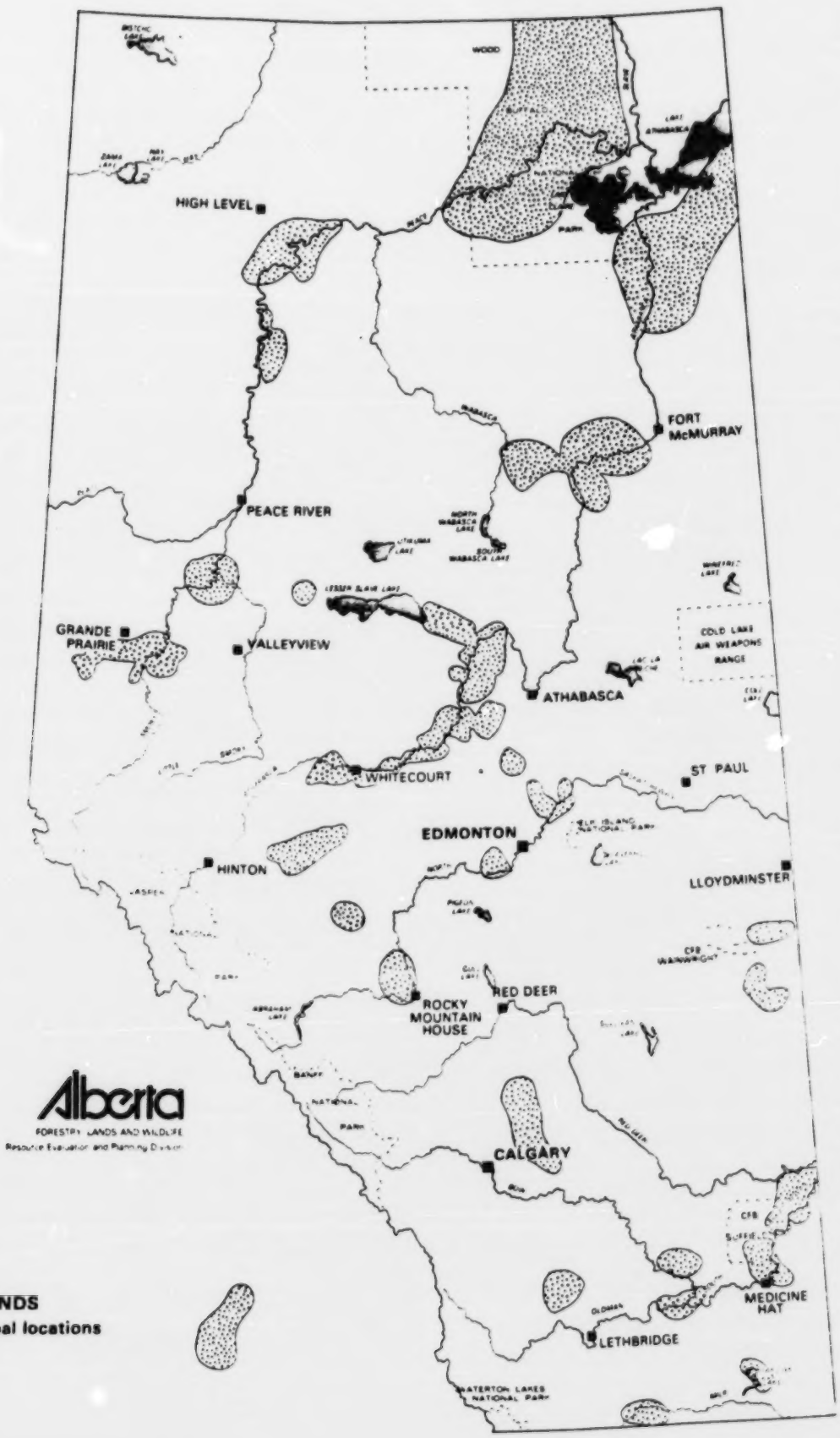


Fig. 1 OCCURANCE OF EOLIAN SANDS IN ALBERTA

David (1977) compiled a report on sand dune occurrence in Canada. His report includes a general description of the dunes known at that time. The report formed the basis for this project. Contributions made by these and other workers clearly set the stage for a comprehensive evaluation of eolian sand deposits in Alberta.

2. METHODS

2.1 Literature Review

A comprehensive review of all published and unpublished reports on eolian sand deposits constituted the starting point of this project. The information obtained from these sources was extremely valuable, particularly since this project had no field study.

In the course of the literature review, special attention was directed to the various types of dunes described. Most reports, however, turned out to be more interested in other aspects than in a discussion of the distribution of the sand dunes in the province. Theoretically, various other reports and articles (e.g., by Bagnold 1941, 1971) were indispensable for this project.

Useful information was obtained from such sources as:

1) Geological Survey of Canada, surficial geology reports.
2) Alberta Research Council - surficial geology reports.
3) Alberta Land Inventory and Canada Land Inventory Maps.
4) Reports by P. David.
5) Exploratory and Reconnaissance Soil Survey reports.

2.2 Interpretation

The data obtained during the preliminary stages of this project were interpreted by the Resource Evaluation Branch, Alberta Forestry, Lands and Wildlife in Edmonton. The interpretation process consisted of an aerial photographic study of the areas where sand dunes had been located in the past as well as any other potential dune areas within the province. This was followed by the computation of the actual areal extent of each dune field.

2.3 Mapping Procedure

The mapping of the eolian landform features was accomplished in two phases. First, all identified areas of eolian landforms were plotted on 1:250 000 topographic map sheets covering the entire province. In all, 41 NTS map sheets were used. Surficial geology maps and reports, soil survey reports and other relevant information were used in mapping the sand dunes in the project area. Upon the completion of the first phase a few selected aerial photographs were re-examined in order to confirm the boundaries of the dune areas mapped.

Phase two consisted of the transfer of all the information plotted on 1:250 000 map sheets onto a 1:1 000 000 base map of Alberta. The map shows all known dunes in the province, including smaller dune areas (less than 10 km^2), which are not described in this report.

The actual distribution of sand sheets in Alberta has yet to be properly evaluated and mapped. The task of mapping these deposits, however, will be immense because they are so widespread and are frequently in motion.

3. FORMATION OF SAND DUNES IN ALBERTA

3.1 Background

Dunes are predominantly particles of sand grains between 0.1 and 0.6 mm in diameter. Most quartz sand grains originated from the disintegration of quartz-bearing rock followed by a process of mechanical abrasion. It is not quite clear what process is responsible for reducing the grains to their sand dune sizes and shapes. It is possible, however, that two processes are among those responsible. These are (a) dry weathering and (b) mechanical action of water and frost.

It is generally known that, in deserts, extremely dry temperature can cause large rocks and stones to split. But there is no general agreement that under these conditions the sand can be reduced to a size as small as, or smaller than, 1 cm. It is not possible either to account for any appreciable reduction in grain size by the action of wind (i.e. in transport). However, evidence gathered from experimental fluvial analysis shows that water and ice can reduce the size of quartz fragments to that of sand grains (Gilberk 1914). This process results in gradual violent grinding and crushing of smaller fragments between bigger ones. On the basis of this available evidence, it seems reasonable to conclude that the vast majority of the sand grains that form sand dunes have been reduced to their present sizes by the action of water, wind or heat, and perhaps ice.

3.2 Sand Supply and Transport

The dune-forming process is long and complex. With sand being the main ingredient in the formation of dunes, its source of supply is crucial for the success of the entire process. Hence, it is

appropriate to give a brief review of sand supply and the ideal landscape that the sand has to pass over in order to reach a suitable settlement and become a sand hill.

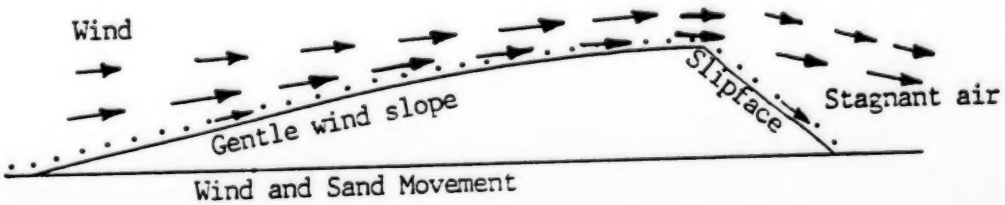
Coastal and riverine dunes have sand produced elsewhere and transported mainly by water current to the shore. Desert dunes, on the other hand, have sand whose place of origin may be an escarpment or a depression where wind erosion is active.

Climatic changes in some locations have had a vital role to play in the development of sand dunes. The parabolic dunes east of Grande Prairie offer a good example. The existence of these dunes suggests that fine and medium sand can be expected beneath the muskegs. Mollard (1983) indicates that during some period following glaciation this region must have experienced semi-arid conditions with little or no vegetation during which dunes were formed. However, as the climate became more humid the water table rose, peat developed and eventually trees invaded the area.

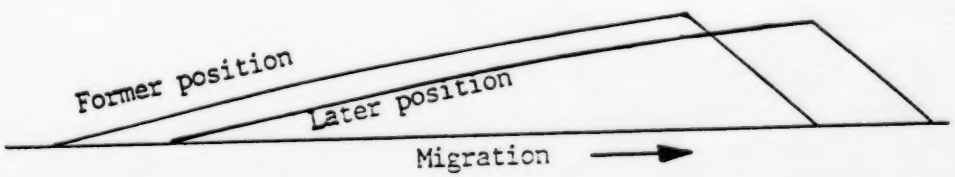
The formation of sand dunes on land is a function of wind velocity and dry weather. When a deposit comprising loose sand particles is left exposed to the wind for a certain time, the sedimentary particles will gradually start to creep. The initiation of eolian transport will depend upon the velocity of the wind (Figure 2).

Other important factors influence the volume of sand transported by wind are the sand size or the grain size distribution, the degree of wetness of the sand and the unevenness of the sand surface.

In the case of coastal or riverine dunes, sand particles washed ashore by wave action can be dried. If the sand remains out of reach of water long enough, it can be readily transported landward or along the shore by wind. Thus the sand which was once part of the sediment load in the wetted coastal zone can be piled up by wind to form sand dunes on land and can occasionally cause the blocking of roads or excessive sedimentation in a harbor.



(a)



(b)

Figure 2. a) and b) Migration of a dune.
After J.D. Mollard, 1983.

Research has shown that although movement of sand under the influence of the wind can occur as surface creep, saltation and suspended movement, the last state is rare because of the large density difference between sand and air. The sheer stress at the sand surface caused by this density is one of the most important factors determining the magnitude of eolian transport. Typically critical stress exists, below which the eolian transport increases approximately with the sheer velocity (Melton 1940).

3.3 Dynamics of Wind Erosion

Unprotected dry accumulation of sand will move constantly under the influence of a strong wind. In the process, every free sand surface will be molded to the shape that presents the least resistance to the wind.

The sand transporting capacity of the wind is chiefly dependent upon the velocity of the wind. Wind passing over unprotected sand becomes immediately burdened with the load that it can transport at a certain velocity. Turbulence is caused by any obstruction. It has the same effect as decreasing wind velocity and results in immediate reduction of the load carried.

The actual amount of material held suspended in the air may amount to thousands of tons over a square mile of wind blown country (Lobeck 1939). Some desert sand storms are hundreds of kms in extent. According to Kerr (1952), a storm 480-600 km in diameter would thus hold more than 50 million m^3 of suspended material. This, however, would represent only the volume of sand in a dune about 30 m high and 3 km across.

It has also been established through laboratory experiments (Bagnold 1941), that the size of particles carried in suspension bears a definite relation to the velocity of wind during storms, being much finer in less violent storms. For any storm, the sizes of dust

particles vary over a wide range with great predominance of those of given size. Bagnold (1941) found in a wind-tunnel experiment that no matter how great the velocity gradient is, the wind velocity at a height of about 3 mm remains almost the same and actually falls nearer the ground as the wind above is made stronger. Bagnold further observed that approximately 22 per cent of the sand moves as creep. The remaining 78 per cent constitutes the movement in suspension and by saltation (Figure 3). The latter method of movement is possibly dominant. Generally, sand is not expected to start moving in appreciable quantities until the wind velocity reaches 24.15 km/h meaning that constant movement takes place during the dry season. the writer believes that 70-80 per cent of all dune movement in Alberta occurs during summer.

3.4 Source Materials

Existing eolian sands in Alberta were derived from a variety source materials. A study of the events leading to the formation of dunes in the province, however, shows that some source sediments played a greater role than others. This is evidenced by the fact that in a number of dune fields one particular source material has been found responsible for the formation of sands in several other areas.

In many dune areas, the source sediments reflect the post glacial environments. In the Wood Buffalo Sand Hills, the source deposits appear to be either glaciolacustrine or glaciofluvial sediments (Craig 1965). According to Bayrock (1961, 1972a, b), however, the source deposits were fluvial, particularly in the vicinity of the Peace River valley. In this particular area, some of the beach ridges west of Lake Claire testify to this development in that they seem to have been severely modified by eolian action. In the Ronald and Richardson Lake Sand Hills, both of which lie to the east and southeast of the Wood Buffalo Sand Hills complex, the source sediments of the sand dunes are the local deltaic (Bayrock 1962, 1972) and other sandy glaciolacustrine deposits (Gravenor and others 1960; Bayrock 1962).

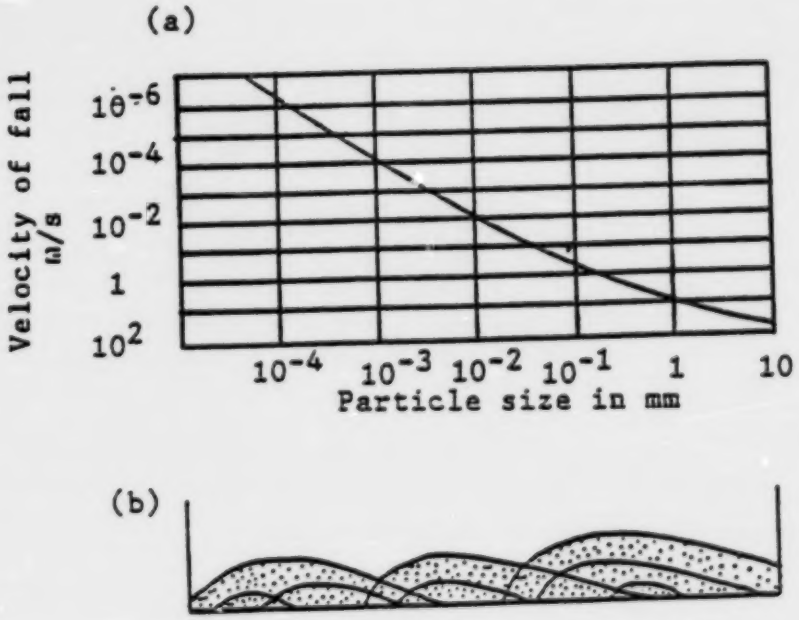


Fig. 3 (a). Variation of settling velocity depending on grain size of particles(after R.A. Bagnold, 1941). (b). Path of sand grains during saltation over a sand surface (after R.A. Bagnold, 1941).

The sands in Fort Vermilion, Cache Creek and Wolverine Sand Hills were formed from shallow water glaciolacustrine deposits. Bayrock (1958) points out that the sands here were apparently deposited in a glacial lake, which formed in front of the retreating ice sheet.

An assessment of the development stages of sands in Fort McMurray Sand Hills shows that the sands here were most likely derived from deltaic sediments. This conclusion is based upon the information obtained from aerial photo interpretation of the area augmented by a study conducted by Lindsay and others (1957). They feel that the source sediments for the sands in the area may have been fluvial sand.

Further south, around Grande Prairie, glaciofluvial and/or glaciolacustrine sediments constitute the main source materials for the sand in the area. Previous studies conducted in the area indicated that deltaic deposits were not as significant (Jones 1966; Henderson 1959; Odynsky 1966). In central Alberta, however, the source material for the sands almost entirely belongs to sandy deltaic deposits. In Nelson Lake Sand Hills, the sands appear to have been derived from sediments of a delta separating Lake Jarvis in the south from glacial Lake Chisholm in the north (Table 1). The deltaic deposits were very important here since they appear to be the dominant source materials for sands in most of the sand dunes in this area. The best known deltaic sediments in the area are those formed in glacial Lake Chisholm which is characterized by widespread muskeg.

St. Onge (1972) conducted studies on the surficial geology as well as the sequence of glacial lakes of Alberta. The results of these investigations indicated that the sands in Redwater, Eastgate and Beaverhill dune areas were developed on deltaic sediments of glacial Lake Bruderheim. On the basis of the local morphology and distribution of the glacial lake, St. Onge concluded that the eolian sands in the area are rather thin and that the dunes now cover a much larger area than did the original deposits.

Table 1

SOURCE MATERIALS FOR SAND DUNES IN CENTRAL ALBERTA
(After St. Onge, 1972, 1975)

	SAND DUNE	SOURCE MATERIAL
1.	Holmes Crossing	Sandy Deltaic of glacial lake Fawcett
2.	Fort Assiniboine	Sandy Glaciolacustrine
3.	Nelson Lake	Sandy Deltaic
4.	Chisholm Bruce Lake, Hondo and Decrene	Deltaic, formed in Glacial Lake Chisholm
5.	Kilsyth Lake	Deltaic
6.	Whitecourt and Fish Lake	Sandy Deltaic
7.	Windfall	Sandy Deltaic
8.	Eastgate	Sandy Deltaic
9.	Redwater and Beaverhill	Deltaic, of Glacial Lake Bruderheim

In Southern Alberta, the sequence of development differs somewhat from those noted above. This is because the area was not subjected to as intense glaciation as the northern part of the province. The sands that form the Middle and Grassy Lake Sand Hills were apparently derived from alluvial fans and lacustrine sands, respectively (Stalker 1969; Westgate 1968). It seems that in the Middle Sand Hills, the alluvial fan deposits were those laid down during the early South Saskatchewan River system, before the down cutting in the valley. Alternatively, the sand may have been derived from shallow water lacustrine deposits as pointed out by David (1977).

It can be noted that considering the distribution of the main source material for the existing eolian sands in the province the glaciolacustrine sandy deltaic and fluvial deposits were most prominent. The lacustrine sands and alluvial fans constitute the chief source materials for the sands in relatively smaller dune areas, particularly those in Southern Alberta.

3.5 Prevailing Winds

Winds play an important role in the movement of eolian sand. Generally, powerful winds of shorter duration are considered more effective than gentle winds of longer duration. In areas with vegetation, final stabilization represents a shift in balance between wind and vegetation with vegetation growth finally gaining ascendancy over the wind.

In Northern Alberta the wind pattern responsible for the formation of both Wood Buffalo and Richardson Sand Hills is complex. In the Wood Buffalo Sand Hills a combination of easterly, northeasterly, southeasterly and northwesterly winds are among the most effective winds. As for the Richardson Sand Hills, southeasterly winds were dominant. The complexities involving the prevailing winds in these two most important dune areas are enormous. It is difficult to distinguish effects created by modern winds from those created by paleowinds.

In the Fort Vermilion and Cache Creek Sand Hills area, the dunes appear to have been under constant effect of the southeasterly and northwesterly winds. According to David (1977), the transverse dunes in the area were formed by northwesterly winds. These dunes are also considered the first to develop in this area. The parabolic dunes, which are modified transverse dunes, were formed by winds blowing just north of west. It is appropriate to note that the effective winds in this area were not reported by Odynsky (1958), in his report on "U-shaped dunes and effective wind directions in Alberta." In the assessment of the prevailing winds in Grande Prairie, Odynsky (1958) points out that the effective winds that might have been responsible for the formation of the sand dunes in this region were from the southwest, having a bearing of 14° north of east at Watino, 6° north of east at High Prairie and approximately 8° north of east at Grande Prairie.

In Central Alberta, the principal winds responsible for the formation of sand dunes in the Windfall-Whitecourt Sand Hills region were blowing from the northwest, approximately 15° south of east at Whitecourt and 36° south of east at Smith and Hondo areas.

The dunes that occur in the Edmonton/Red Deer area (Redwater, Eastgate, Beaverhill, Stony Plain Sand Hills), appear to have been formed mainly by winds gusting from the northwest, at a bearing ranging between 20° and 50° south of east (Odynsky 1958; David 1977).

The pattern of the effective winds responsible for the formation of dunes in Southern Alberta exhibits great variation. The eolian sand dunes at Rosebud and the small dune areas around Bassano were apparently formed by northwesterly winds while larger dune areas (Middle, Grassy Lake and Pakowki Sand Hills), appear to have been formed by winds blowing from the southwest having a bearing of 12° to 25° north of east.

3.6 Major Dune Areas

The distribution of dunes in Alberta can be grouped into two important divisions, namely the north/central group and the southern group. Dune occurrences in the north/central group are larger in area while the southern dunes have smaller areas and are more active.

For the purpose of this study, eolian landforms in Alberta can be subdivided into seven major groups:

a) Richardson Lake Sand Hills
b) Wood Buffalo Sand Hills
c) Fort Vermilion/Cache Creek Sand Hills
d) Grande Prairie Region South Hills
e) Windfall/Whitecourt Region Sand Hills
f) Redwater/Eastgate/Beaverhill Area Sand Hills
g) Grass Lake/Bowmanton/Middle Area Sand Hills.

Of these, the largest is the Wood Buffalo Sand Hills covering approximately 3 220 km^2. The lower Peace River cuts through this large dune area. The Richardson Lake Sand Hills is made up of several small sand dune fields located close to one another. The portion of the Richardson Lake Sand Hills that lies within Alberta ranges from 800 to just over 1 600 km^2. A portion of the Richardson Lake Sand Hills lies within Saskatchewan.

Fort Vermilion/Cache Creek Sand Hills extend about 640 km^2, while the sand dunes in Grande Prairie area cover a combined area of approximately 416 km^2 including Watino Sand Hills. The eolian sand dunes that form a chain from Edson through Whitecourt and Assiniboine to Hondo are comparatively smaller when considered individually, but together they cover a surface area well over 800 km^2.

The principal sand dune area in Southern Alberta covers just over 230 km^2. This is the Middle Sand Hills. The remaining dune areas are relatively small although many of them can be considered important locally.

3.7 Qualitative Comparison of Dune Areas

The distribution of eolian sands in Alberta varies in size and quality. A comparison of the quality of the eolian sands in the province, therefore, would reflect various aspects of the sand dune areas.

Large sand dune areas show a complex network of both minor and principal dune forms. The presence of the two forms result in these areas having various dune qualities. The Wood Buffalo Sand Hills, for example, are made up of small dune areas which, when considered collectively, cover an enormous area with a significant diversity of dune types. If these dunes were considered individually they would seem very insignificant both in size and quality. Along with the small dune areas, however, are fairly large erosional, individual and composite dune forms which can be characterized as high quality dunes.

There is a big difference qualitatively between small and large dune areas. Most large sand dunes display a variety of dune types. This appears to be the case in both Wood Buffalo and Richardson Lake Sand Hills. Within these two major dune areas there are large parabolic dunes, sand ridges, U-shaped, V-shaped and longitudinal dunes. In smaller dune fields, for example, Edson, Hilda or Redwater Sand Hills, the picture is totally different. In general, these fields consist primarily of two major dune types. Occasionally, dunes in small fields are active and poorly defined.

Qualitative comparison of the dune areas in Alberta can also be based upon the terrain where the sand dunes are developed. In the Fort McMurray dune fields, the parabolic dunes can be characterized as poor, as they are not well developed. Most areas are saturated with water and any dunes observed have developed on the crests where it is dry.

On the other hand, the dunes found in Grande Prairie and Central Alberta generally are of better quality. Most of the dunes that occur

in these areas are vegetated and hence stable compared with the dunes in Southern Alberta. The stabilization has to a large degree contributed to the preservation of their eolian relief. Consequently, these sand dunes are easily discernible on aerial photographs.

The sand dunes in Southern Alberta are affected by the dry conditions. The ground is drier and there are fewer wetlands. These conditions result in the local dunes being constantly active. The winds here are severe and more frequent, which results in poor preservation of eolian relief. Instead of well-developed parabolic dunes there are elongated dunes in the Middle Sand Hills and blowout hollows and elongated dune tongues in Grassy Lake Sand Hills. The quality of the dunes here is hampered by the constant movement of the eolian sands.

4. CLASSIFICATION AND DESCRIPTION OF EOLIAN LANDFORMS IN ALBERTA

4.1 Background

Under the stimulus of aridity, wind scour becomes an erosive agent more constant than rain and, at times, more persistent throughout certain periods than the sea. The factors which encourage eolian sand movement are varied and complex. They include deficient rainfall, high evaporation, sparse vegetation and seasonal winds.

The areal extent of sand dunes in Alberta is far greater than in any other province in Canada. The Wood Buffalo Sand Hills in Northern Alberta is the largest single dune area in the entire country. Dunes in Alberta occur in a variety of forms and types.

For the purpose of this study, David's classification (1977) of eolian and noneolian landforms has been adopted. Using this classification, all eolian landforms greater than 10 km^2 can be subdivided into five major categories:

a) Erosional forms
b) Individual dune forms
c) Composite dune forms
d) Dune ridges
e) Sand accumulations void of eolian relief

4.2 Erosional Forms

Erosional forms of sand dunes comprise blowout dunes; blowout hollows and wind pits. Blowout dunes are actually dunes on dunes in that a crevasse - also known as breach in dune - is a depression produced by deflation on a formerly stabilized dune. Wind pits and

blowout hollow sand dunes are basically depressions formed by sand deflating through a breach in vegetation cover or through other forms of surface protection.

Good examples of blowout dunes mentioned above are found in Grassy Lake and Edgerton Sand Hills in Southern Alberta. In Northern Alberta, around Westlock, the same dune forms but on a smaller scale, have also been identified. The sands in the Grassy Lake Sand Hills were derived from lacustrine deposits (Westgate 1968), and appear to be rather thin. The dunes in the Grassy Lake Sand Hills are oriented in a northeasterly direction and, except for the fact that a few other dune forms are found in the area, these sand dunes are neither unique nor particularly significant.

Besides being found in the Grassy Lake dune field, blowout dunes are predominant in the Middle Sand Hills. The sand hills can be divided into three: the northern, the southern and the Cavendish sectors. In the southern section, wind pits have developed on most of the dunes. The source sediments for these sand dunes may have been alluvial fan deposits laid down by the early South Saskatchewan River system before the down-cutting in the valley (Stalker 1969), or they are thin lacustrine deposits. These dune forms are also well developed in the Cavendish sector, where the blowout dunes cover most of the western part. These dune types are probably better developed in the Middle Sand Hills than anywhere else in the province. In this area the blowout hollow and wind pits are widespread over large areas and appear to have developed on thin source sediments. They, however, do not have any notable significance or uniqueness except, perhaps, for the effect of the Saskatchewan River valley on the development of the dune.

Extensive dunes are found in an area northeast of Lake Pakowki and in the vicinity of the Oldman River. In the Lake Pakowki area, lacustrine sand has been blown onto the adjacent ground and end moraine by western winds. The sand extends onto the till as a group of lobes convex to the east, within which exist blowout dunes. These thin lobate

sheets of sand, together with their superimposed dunes, are now stabilized by grass, shrubs and trees, but in some places have been reactivated as a result of prolonged drought.

In the Westlock Sand Hills area, the blowout dunes are morphologically poorly developed and mostly lined up with vegetation in a semi-stabilized state. There are blowout hollows and wind pits in other areas but the occurrence in those areas is not significant enough to warrant a detailed description.

4.3 Individual Dune Forms

4.3.1 Parabola Dunes

Parabola dunes constitute the dominant dune type within the individual dune form category in Alberta. These dunes and their associates have been recognized in most of the major sand hills in the province. The parabolic dunes which have an arcuate shape in plain view are easy to identify on aerial photographs. Generally they occur as open or filled-up dunes (Figure 4).

In Northern Alberta parabola dunes, as most other dune types in the area, were developed from glaciolacustrine and glaciofluvial deposits and from fluvial deposits in the vicinity of Peace River (Bayrock 1961; Craig 1965).

Parabola dunes are the dominant dune type in the Wood Buffalo, Richardson Lake, Fort Vermilion, Cache Creek and Fort McMurray Sand Hills. Most of the parabolic dunes in these areas are asymmetrical, however, elongated parabola dunes are also common.

The size of the dunes varies from one area to another. The dunes found in the Fort Vermilion and Cache Creek Sand Hills are smaller than the dunes in the Wood Buffalo and Richardson Lake Sand Hills. Unique geomorphic processes have created the sand dunes in the Wood Buffalo and

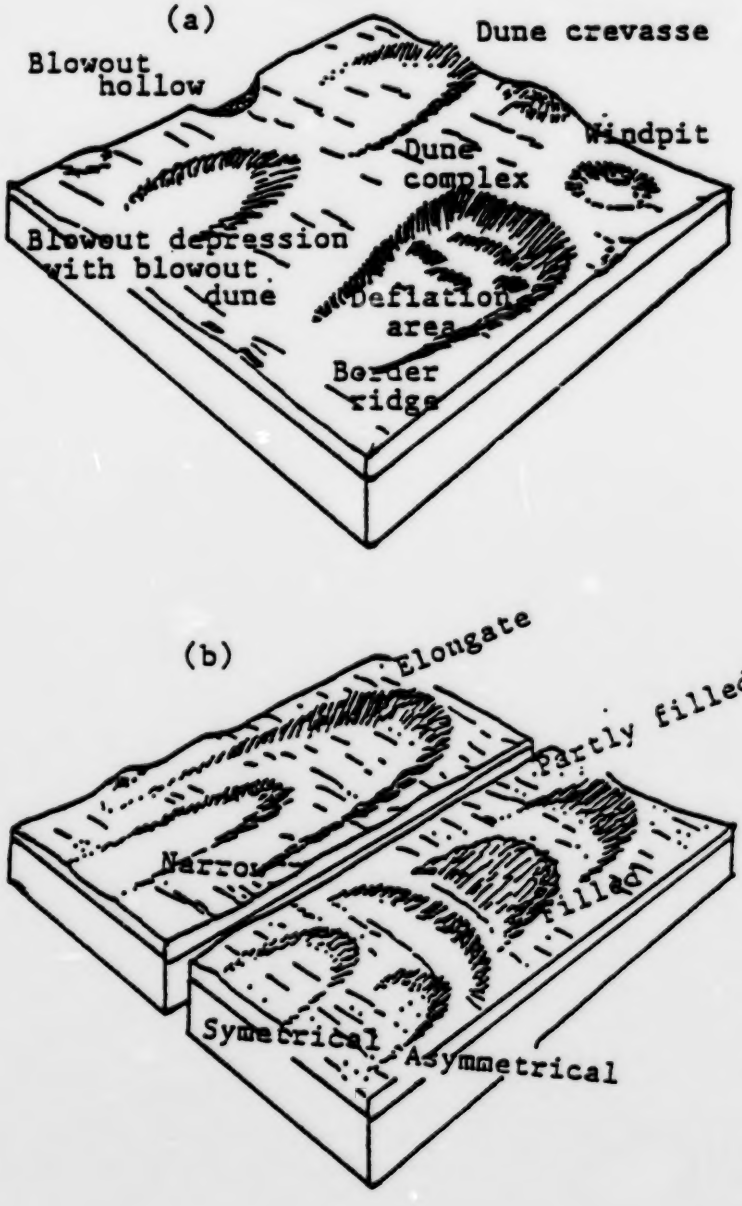


Fig.4 a) Moist sand forms-Erosional, after P.P. David, 1977a; b) Moist sand forms-Parabolic dunes after P.P.David, 1977b.

Richardson Lake areas. The fluvial sands derived from the Peace River floodplain have been subjected to eolian action and consequently most of the area underlain by these sands support numerous sand dunes.

Eolian sands in the Wood Buffalo and Richardson Lake areas overlie most of the fluvial, lacustrine and old deltaic sands. All of the sand dunes in this area are semi-arid and include the parabolic, U-shaped, blowout, migrating variety and longitudinal dunes. The U-shaped and longitudinal dunes are made up of ine to medium-grained sands. The area also contains fish hook dunes which developed mainly on the old deltaic sands. Most of the dunes in the area have been stabilized by vegetation except for the occasional blowout. The stabilized dunes were formed by winds from the southeast while the active blowout and migrating sand dunes are being created by winds from west-northwest. A dramatic change in climate is evident from the deflation basins of the old stabilized sand dunes which are now filled by muskeg or water. It is theorised that the old stabilized sand dunes were formed in a drier climate when the water table was much lower than it is at present.

In the Wood Buffalo and Richardson Lake Sand Hills region, smaller, but well-formed, pseudo-dune forms, with elongate parabolic patterns have been observed. These dune forms are morphologically interesting in that they differ from the other fairly common parabolic dunes which are also well represented in this area. These rare forms are believed to have been derived from the outcrops of the horizontally bedded Devonian strata (Douglas 1970).

Within the Wood Buffalo Sand Hills, filled parabola dunes have been located in the southwestern dune area. This is the only area in Canada that has such dune features. The dune form is accentuated by the differential vegetation growth. This in turn differs from the wetlands in the low-lying interdune areas.

Parabola dunes are also well developed in Cache Creek Sand Hills. Most of the parabola dunes observed here are characterized by short wings. A detailed aerial photo interpretation reveals that they area better developed in the northern sections of the dune field, where they extend over the east side of Cache Creek. The dunes, which are transitional in form between the transverse dunes and small parabola dunes, were developed by the westerly winds. These transitional forms are observed on aerial photographs as small, faint, straight ridges or as small parabola forms superimposed upon the larger transverse dunes.

In the Peace River district, large areas of eolian sands and silts are found adjacent to most of the major rivers and streams. These eolian deposits cover large areas of glaciofluvial sands and gravels. Some thin eolian deposits are also found over glaciolacustrine and till deposits (Jones 1966). The present vegetation cover has stabilized the dunes and only where humans have removed this protective cover do blow-outs and active movement of sand occur. In most instances sand has not been driven far beyond its area of original deposition.

A ground water study of the Peace River district (Jones 1966), indicated that in areas covered by eolian deposits, shallow water wells could be completed to supply water for domestic and stock purposes. Yields of water in the dune areas, however, should be low (in the order of 7 to 10 litres per minute) because the deposits are usually thin (up to 9 m). These are basically water table aquifers and respond to seasonal fluctuations in precipitation.

The Fort McMurray Sand Hills also have notable characteristic features. From aerial photo interpretation, the dunes in Fort McMurray Sand Hills appear to have been derived from sandy deltaic deposits (Lindsay 1957). Much of the area is covered by wetlands and only those sections of the dunes that project above the wet areas are clearly visible on aerial photographs.

The dunes in the Fort McMurray Sand Hills are almost entirely of the parabola type. They were formed by winds gusting from the east. However, near the western border of the sand hills some dunes show developments by westerly winds (David 1977). The dunes located in the low-lying area have been stabilized by vegetation, while the dunes on the higher and better drained sites continue to be active. The continued activity is a result of the reorientation of the wind directions in this area. This change in wind pattern has been observed in several areas in Northern Alberta.

In Western Alberta, sand dunes occur extensively in the Grande Prairie region. Eight individual fields have been identified. They are the Wapiti, Pinto Creek, Smoky River, Economy Creek, Ellenwood Lake, Bear River, Grovedale and Pipestone Sand Hills. To the north lie the Watino Sand Hills.

Sand dune development in the Grande Prairie region has been investigated in some detail by Thornbury (1954) and Odynsky (1956), who respectively described the dunes as barchan and U-shaped. Further studies, however, indicate that open parabola dunes also occur in this region (David 1977). Parabolic dunes are best represented in the dune fields located just south of the Peace River valley (Wapiti and Smoky River Sand Hills). The sands in these areas occur on sandy and silty calcareous materials.

A study of the aerial photographs covering the eastern parts of this region shows that most of the dunes in this area are similar. This resemblance can, in part, be attributed to the dune-forming winds which prevailed from the southwest. Similar parabolic dunes have been located at Watino. At High Prairie, the winds which formed the nearby dunes were also from the southwest.

It is interesting to note that all the dune fields in the Grande Prairie region, except one, are situated along the Wapiti and Smoky Rivers and extend for over 32 km. The Watino Sand Hills to the north of

the main Grande Prairie dune areas cover approximately 16 km^2. The dunes in the Watino Sand Hills have been described by Henderson (1959). In his discussion, Henderson describes low mounds of wind transported silts as dunes. However, David (1977) does not classify such accumulations as dunes.

According to Jones (1966), Odynsky (1958) and Gravenor and others (1977) the sand dunes formed in this region were derived from glacial outwash sands and gravel deposited in high level terraces or from lacustrine sediments.

Within the Grande Prairie dune region, two main dune associations exist. The first is formed by a combination of open parabola and V-shaped dunes; the other consists of elongated parabolic dunes. It must be emphasized, however, that despite the occurrence of several other dunes types in the region, parabolic dune types are the most widespread in the region. In the eastern and northern sections of the dune area, the terrain surface expression varies from low to moderately high elevations. Well-drained, elongated parabolic dunes occur in the higher terrains and open parabolic dunes are found on poorly drained low-lying areas.

The most extensive parabolic dunes in the entire Grande Prairie dune region are found in Beaver River Sand Hills. This dune field covers more than 97 km^2 and most dunes in the area are parabolic. Some of the dunes in the Beaver River Sand Hills form composite arrangements of the "en echelon" type (Figure 5c). The inter-dune areas are almost exclusively covered by moss bogs.

In all areas occupied by open parabola dunes, interdune surfaces are covered by thick peatland vegetation with a few open lake surfaces. In areas occupied by the elongate parabola dunes the reverse is true. The interdune areas are either free of peat or support only shallow peat or swampy terrain. Wherever the two dune associations occur side by side, the change from one association to the other occurs concurrently with the appearance of the peat (Odynsky 1958; David 1977).

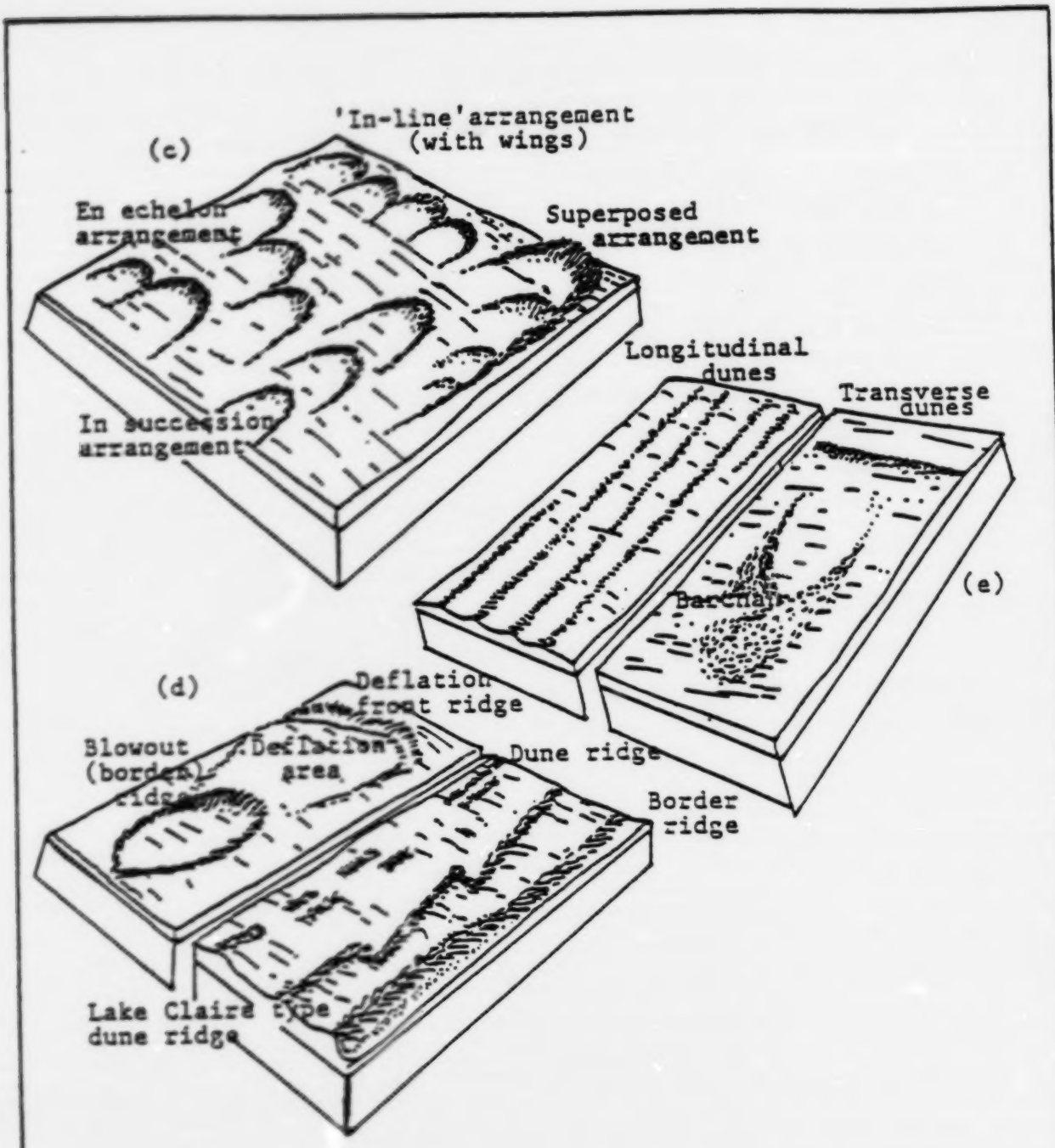


Fig. 5, c) Moist sand forms - composite dune, after P.P.David, 1977a.; d) Moist sand forms - dune ridges, after P.P.David, 1977a; e) Principal dry sand forms, after P.P.David 1977a.

The development of parabola dunes in other dune fields within the Grande Prairie dune region is limited and to a certain degree very insignificant. The dune areas of Wapiti and Pipestone Creek, Grovedale and Economy Creek are considerably smaller (from 8 to 80 km^2). The Ellenwood Lake Sand Hills area, which in fact is larger in areal extent (106 km^2) than the Bear River Sand Hills has both open and elongated parabola dune types. However, the parabola dunes here occur in distinct areas and are less widespread. The elongated parabola dunes are formed at slightly higher elevations than the dunes of other associations. The open parabola dunes occur at lower elevations and the interdune areas are covered with wetlands.

Unlike the sand dunes in the Grande Prairie region where the dunes are concentrated in a small area, the dune fields of Central Alberta are both larger and more extensive. The sand dunes here consist of more than 15 major dune areas, covering more than 1 200 km^2. The dune extends from Edson through Whitecourt and Fort Assiniboine to Hondo and Slave Lake areas. Also included are the sand hills which lie to the northeast of Edmonton as well as the Brazeau and Rocky Mountains Sand Hills.

The source deposits for the sand dunes in this area are similar to those in the Grande Prairie region (Table 1). The only difference is that the Central Alberta dune field is three times larger than the Grande Prairie dune field.

The developmental factors of parabola dunes in Central Alberta appear to be far more important than they are in Grande Prairie. In the Edson Sand Hills area all the dunes belong to the parabola family. They display, however, distinctive features depending upon their location. In the western part of the Edson Sand Hills, for example, the dunes occur directly over the source deposits. In this area the dunes are almost entirely of the filled parabola type. In the east, open and elongated type parabola dunes are well developed. Unlike many other dune areas in Central Alberta, the dunes in the Edson Sand Hills are stabilized by dense vegetation.

Situated just north of the Edson Sand Hills are seven dune fields which constitute the Windfall-Whitecourt Sand Hills group. The dunes in the five areas that form the Windfall Sand Hills are all of the parabola type. The source deposits for the sand dunes were deltaic sands. David (1977) observed that the two westernmost dune fields contain elongate dunes. Aerial photo observations, however, have indicated that almost all dunes in this area belong to the asymmetrical parabola type. One small dune field in the extreme northwest clearly shows minor occurrences of stabilized elongated parabola dunes. The morphological attributes of most of these dunes as well as their density of occurrence suggest that the dunes to the east apparently developed on thicker sands than those to the west. A careful evaluation of the Windfall Sand Hills sheds light on an eolian landform development theory inconclusively assessed until now. It appears that the thickness of available dry sand for deflation must have been controlled by ground water levels which in turn must have also been controlled by lake levels in the respective basins. A more detailed analysis of the Windfall Sand Hills is unnecessary in light of the small area occupied by these sand dunes.

East of the Windfall Sand Hills are Whitecourt and Fish Lake Sand Hills. These two dune areas together cover approximately 80 km^2 and both are developed on sandy deltaic deposits. The main dune types are elongated parabolas with a low density of dune occurrence. In the Fish Lake Sand Hills area slightly higher concentrations of dune were observed. The eolian form features are poorly developed.

Extensive areas of sand dunes occur northeast of the Whitecourt-Fish Lake Sand Hills area. The major dunes here include the Holmes Crossing, Fort Assiniboine, Nelson Lake, Kilsyth Lake, Chisholm, Bruce Lake, Hondo and Decrene fields. Most of the dunes in the sand hills are morphologically poorly developed and have been formed by prevailing southeasterly winds. The main dune types are transverse with embryonic barchan forms (e.g., in Holmes Crossing and Fort Assiniboine), surrounded on all sides by parabolic dunes stabilized by vegetation. Most of the parabolic dunes form composite "in-line" arrangements. It is also possible that these parabolic dunes were derived from primary transverse dunes (David 1977).

The development of parabola dunes in the Chisholm, Bruce Lake, Hondo and Decrene Sand Hills does not differ much from the other sand dune areas in the vicinity. All four occurrences apparently developed on deltaic deposits which formed in Glacial Lake Chisholm (St. Onge 1972, 1975). They are all characterized by a widespread occurrence of open lakes, peatland and swamps. Parabola dunes, elongated parabola and V-shaped dunes are the dominant dune types found in all four dune areas. Many of the dunes here do form "en echelon" type composite arrangements. The dunes appear to be in an early state of stabilization.

The discussion of the development of parabola dunes in Central Alberta would be incomplete without a review of the occurrence of these dune types in Redwater, Eastgate and Beaverhill Lake Sand Hills. All these sand dune occurrences are located between 32 and 64 km northeast of Edmonton. They are all small in areal extent (under 30 km^2 on the average) and two of them (Redwater and Beaverhill Lake Sand Hills) are developed on deltaic deposits of Glacial Lake Bruderheim (St. Onge 1972). The Eastgate Sand Hills developed from glacial outwash deposits. In all three dune fields parabola dunes are the dominant dune types. The size of the dunes, however, are much smaller than those in Northern Alberta. The parabolic dunes in the Redwater dune field are elongated with arms as long as 2 km. The size of the dunes in the other two areas are much smaller. The occurrence of parabolic dunes around Red Deer is minor. This is also evident in the scattered sand fields near Rocky Mountain House.

In Southern Alberta (south of Red Deer), eolian landform features are both much more scattered and smaller in area compared with the dunes in the central and northern regions of the province. According to David (1977), they may have been formed during the climatic optimum.

Localized sand dunes are found in many areas in Southern Alberta. Notable areas are the Carmangay and Rosebud Sand Hills. Most of the sand dunes in this part of the province were formed by prevailing south-west or west-southwest winds. Many are fairly recent and are generally small blowouts and parabolic types formed in the basin of Glacial Lake Carmangay.

Most sand dune areas in Southern Alberta have been reactivated. This results from the disturbance of the vegetation cover which consists of short prairie grass and occasional shrubs that can dry up even after a mild disturbance. Similar developments have been observed in certain parts of Central Alberta, where intensive farming is practised. It is possible that continued disturbance of vegetation through over grazing and farming will escalate the reactivation process of many dune areas, especially in Central and Southern Alberta. The major sand dune area in Southern Alberta is the Middle Sand Hills covering approximately 240 km^2. Nearby are the Grassy Lake Sand Hills (39 km^2), Bowmanton Sand Hills (45 km^2) and the Pakowki Sand Hills (30 km^2).

The Middle Sand Hills are located on the west side of the South Saskatchewan River valley and extend north to cover about 35 km^2. In the northern section of this dune field parabolic dunes are widespead. Most of these dunes are either half filled or filled parabola.

Parabola dunes in the Grassy Lake Sand Hills are limited in areal extent. David (1977) pointed out that some of these parabola dunes form composite arrangements of the in succession type (Figure 5c). The blowout constitutes the principal sand dune type in the Grassy Lake Sand Hills.

Parabolic and longitudinal dunes are evident in the Pakowki Sand Hills. These dunes were formed by prevailing west-southwest winds. The main source deposits are the lacustrine sands which overlie the Oldman End Moraine. Some of the parabolic dunes in this field are linked parabolic dunes and are now stabilized by vegetation.

4.3.2 U-shaped and V-shaped Dunes

Studies of the distribution of sand dunes in Alberta have confirmed the occurrence of U-shaped and V-shaped dunes in many parts. U-shaped and V-shaped types along with blowouts and parabolic dunes were classified by Smith (1949) as common in semi-arid and humid areas. Smith pointed out that barchans are the typical dune types in desert areas.

In Alberta U-shaped dunes and their effective wind directions have been investigated and documented by Odynsky (1957). The present study tries to shed light on a few dune areas not covered during earlier investigations and to outline the present dune conditions in those areas.

As outlined above the dunes that occur in Northern Alberta are predominantly of the parabola type. However, U-shaped and V-shaped dunes also occur in parts of the Wood Buffalo and Richardson Lake dune areas. In these two areas other dune types are overshadowed by the frequent occurrence of the parabola dunes. This distribution of dunes is also common in the Fort McMurray and Cache Creek dune fields.

In the Grande Prairie area U-shaped and V-shaped dunes are fairly well represented. Thornbury (1954) thought that these dunes were the barchan type, while the American Geological Institute (1956) referred to the same dune as U-shaped and parabolic respectively. Out of the seven dune fields in the area, the largest area of the parabola type is found south of Grande Prairie, and is known as the Wapiti Sand Hills. The second important area is the Smoky River Sand Hills located just east of the Wapiti dune field. According to Odynksy (1958), these dunes have formed on sandy and calcareous materials on some of the upper terraces of the Wapiti and Smoky rivers. Winds prevailing from the northwest molded the sand into U-shaped forms with blowout pits which are later infilled with peat. These dunes are now stabilized by thick grass cover, aspen poplar, pine and shrubs.

Similar dune types are found at Watino. These dunes, apart from the fparabola type seen earlier, are more of the V-shaped than U-shaped types. The dune forms at Watino resemble those of the Grande Prairie region. Odynksy (1958) describes most of these dunes as having longer arms than the dunes in the Grande Prairie area while David (1977) thinks that the opposite holds true. Our study of the aerial photographs indicates that the dunes in this area are not very discernable on aerial photographs. Consequently, any firm description of these dunes as to

size and extent is not possible at this time. The effective winds in the area are from the southwest between 8° and 15° north of east (Odynsky 1958).

Aerial photographs also reveal that similar dunes are found in the Whitecourt, Athabasca, Edmonton and Red Deer areas. The arms of most of the U-shaped dunes in the central and northeast sections of Alberta are longer than those of the dunes found in Grande Prairie area (Odynsky 1958). Some of these dunes have arms longer than 1.6 km.

The longitudinal dunes have been stabilized by spruce, grass, poplar and aspen. The dunes have been formed by winds prevailing from the northwest at a bearing of between 15° and 50° south of east.

Recent wind-blown sands mantle the surface of outwash deposits east of the Battle River in the Hardisty district. The outwash sand has several dunes which are still active. The U-shaped dunes common in this area were probably developed under past semi-arid conditions. the dunes comprise fine to medium grained glacial sand derived from nearby glacial outwash (Bayrock 1957).

The sand dunes were produced by winds which blew from the northwest, the same direction as the winds which formed dunes in the Sedgewick and Allience Brownfield districts (David 1977).

In Southern Alberta U-shaped and occasional V-shaped dunes have been observed in the vicinity of Calgary, Lethbridge and Medicine Hat, a much drier area of the province. some of the dunes in these areas are still active. A large expanse of stabilized U-shaped dunes occur north of the Bow River valley. Many of these dunes have become active owing to the disturbance of the vegetation cover by overgrazing and cultivation. The region also experiences greater variation in the direction of effective winds. In some parts the effective winds are from the northwest about 20° to 30° south of east (Rosebud Sand Hills). In others the winds responsible for the formation of U-shaped dunes are from the southwest 12° to 25° north of east (Carmangay and Grassy lake Sand Hills).

4.3.3 Transverse Dunes

Transverse sand dunes are predominant in the northern dune fields such as Fort Vermilion and La Crete Sand Hills area. Transverse dunes are particularly common in Fort Vermilion Sand Hills (Figure 5e). The transverse dunes show a greater diversity than other dunes in Alberta. They may have been affected by various wind directions during their transformation. David (1977) recognized three distinct sets of transverse dunes in the area. The first set of transverse dunes was formed by southeast and later modified by northeast winds. A third set was formed by east winds. The presence of several sets of transverse dunes, coupled with partial deformation and reorientation, renders the morphology of these dunes unique not only in Alberta but Canada as a whole (David 1977).

Perhaps the most noteworthy occurrence of transverse dunes in Alberta are the ones in the Holmes Crossing Sand Hills of the Whitecourt region. This dune area is unique in that the transverse dunes are surrounded almost entirely by stabilized parabolic dunes, some of which clearly show transitional forms. The transverse dunes occur in the low-lying northwestern section of the dune field. A similar dune pattern is observed in the adjacent Fort Assiniboine Sand Hills to the north. The transverse dunes in this area are partially preserved.

Similar but morphologically different dunes are found in the Wood Buffalo Sand Hills. Smaller transverse dunes are located in the vicinity of Peace River with prevailing winds from the east and northeast. However, more detailed study of the local prevailing winds is still required in order to establish a chronology in which the different wind directions affected the dunes in the area.

4.4 Composite Dune Forms

Composite dune forms are sparsely distributed throughout Alberta. Quite often aerial photographs reveal two similar dune types attached side by side. Dunes have been observed that were formed by the joining of a series of U-shaped dunes individual dunes often attached to one another. The principal dune types in this group are zigzag, twinned and dune tongues.

4.4.1 Zigzag and Twinned Dunes

A study of the distribution of sand dunes in the Wood Buffalo Sand Hills has shown that the zigzag type dunes are fairly widespread. Zigzag dunes have been located in areas where V-shaped dunes occur. It can be deduced from this fact that the two are closely associated. The zigzag dunes might have been formed as a result of the joining of one or more V-shaped dunes. The zigzag dunes in the Wood Buffalo Sand Hills appear to have formed this way. Most of the dunes are characterized by the formation of common composite arrangements of the in-line and en echelon type (Figure 5). This setting is better recognized in the northern parts of the Wood Buffalo Sand Hills area.

In orther areas these types of dunes are formed from the original clustering of the primary parabola dunes. The zigzag pattern can reflect the presence of former dunes. In Saskatchewan, zigzag patterns have been associated with ridge dunes (David 1977). This shows that a variety of developmental forms of zigzag dunes can be expected.

Similar dunes types displaying prominent zigzag patterns occur in the Richardson Lake Sand Hills where the ridges dominante the local landscape. This same area also shows the development of twinned dunes a very small scale. Perhaps the best developed twinned dunes are in the Chisholm, Bruce Lake and Hondo Sand Hills of Central Alberta. These dunes are formed in the same way as the in-line arrangement. The only difference here is that instead of having several dunes in the form of complete series, we now have only two distinct dunes joined together to form the twinned dunes.

4.4.2 Dune Tongue

Besides the two types discussed above, dune tongues constitute another dune type found in many areas in Alberta. The dune tongues, however, are neither well defined nor fully analysed. This shortcoming is perhaps because although the dunes occur in many parts of the province, they are morphologically insignificant. Within the map area, dune tongues occur in the Ellenwood and Economy Sand Hills of the Grande Prairie region. In the Ellenwood Sand Hills, dune tongues extend in the northeastern part of the area for approximately 8 km from the body of the dune field. These adjoining terrains also resulted from dune migration. The dunes were probably derived from outwash deposits which may have been reworked by glaciolacustrine action before they were exposed to the winds (Henderson 1959). In the Economy Creek Sand Hills a dune tongue occurs in addition to the transitional parabolic and elongated parabolic forms. The dune tongue is located in the eastern corner of the main dune field. The dune appears to have stabilized within the dense vegetation that surrounds it.

In Central Alberta, aerial photo interpretation of part of NTS sheet 83H, Edmonton, indicated small, rather scattered dunes with narrow downwind extensions. These dunes consist of a variety of types which must have migrated from a main body of dune area. If this assumption is correct, then the dunes in the area (Redwater/Bruderheim) have all migrated relatively far from their source.

4.5 Dune Ridges

Dune ridges, also known as sand ridges, are elongate or curvilinear features of wind blown sand. These features are formed either by deposition of eolian sand or erosion of formerly wind-built sand dunes.

Several types of dune ridges are evident in Alberta. This discussion will concentrate on the types recognized in Alberta. These are sand ridges (or dune ridges), border ridges, fish hook, blowout ridges and lacadena-type sand ridges.

4.5.1 Sand Ridges or Dune Ridges

Geographically, the distribution of sand ridges in Alberta is limited. Sand ridges are better developed in the Wood Buffalo, Richardson Lake and Ronald Lake Sand Hills, but mostly widespread in both Richardson and Ronald Lake Sand Hills. The ridges lie parallel at a distance of approximately 0.3 - 1.6 km.

The dunes form composite arrangements of the in succession type. In this pattern the parabola, sand ridges and in certain areas, fish hook types are arranged so their right, northeast wings form a common ridge. The resulting sand ridge resembles the well-known Lake Claire sand ridge, which shows well defined zigzag patterns (Figure 5).

In certain areas of the sand hills these dune ridges dominate the landscape and as observed by David (1977), they can be seen along the axial centre of the dune area tending in a northwesterly direction. The inter-ridge areas have a few individual dunes on them and are partially covered by peat with the crestline of the buried dunes visible. Locally, within the Richardson Lake Sand Hills, are dunes which show the different stages of development of this type of sand ridge. These include fish hook dunes, which are normally attached to one another and already appear as dune ridges.

David (1977) points out that the easternmost sand ridge in Alberta runs parallel to the Richardson River and is classed as a border ridge which is different from the Lake Claire type dune ridges. The Lake Claire type dune ridges are located in the centre of the Richardson Lake Sand Hills. Their presence in the centre of the sand hills could suggest that there was less sand available for deflation than in areas where parabolic dunes are dominant.

In the Wood Buffalo Sand Hills area linear dune ridges have been observed (Mollard 1983; David 1977). These ridges were formed when sandy deltaic outwash sediments were gradually terraced by stream erosion and modified by wind. Linear dunes were apparently formed by the elongation of one or both wings of the parabolic dunes, while the dunehead was advancing rapidly. In places this resulted in a single linear ridge, while in others nearly parallel or slightly converging ridges formed. Locally, the elongate dunes show the stabilizing effect of vegetation, particularly on the northeast side of the Wood Buffalo Sand Hills. The inter-ridge areas are covered by parabolic dunes, which apparently were formed during and following the formation of the ridges.

Besides being concentrated mainly in the Richardson and Wood Buffalo Sand Hills, dune ridges have been located in both the Edgerton and Buffalo Park Sand Hills. The last two sand hills are located in an area covered by topographic map NTS sheet 73D, Wainwright. Here the dune ridges are associated with the North Battleford type sand ridges, which occur mainly in the northern half of the sand hills. The North Battleford type of sand ridge can also be classified as longitudinal dunes (Gravenor and Ellenwood 1957; Bayrock 1958a). In northeastern Alberta, longitudinal dunes grade into dune ridges. Within the Buffalo Park Sand Hills the dunes are oriented northwest to northeast. Activity in the eolian sand areas is restricted to the south side of dune ridges.

4.5.2 Border, Harpoon and Lacadena Sand Ridges

The occurrence of border ridges, harpoon and lacadena sand ridge types in Alberta is very limited. Border ridge dunes have been recognized in the Richardson Lake Sand Hills. Their formation and general morphology is similar to that of the sand ridges described above.

Lacadena sand ridges form the main dune type in the Wolverine Sand Hills located south of the Fort Vermilion Sand Hills. These dune ridges are usually characterized by a central low axis with slip face

line slopes along both sides. In the Wolverine Sand Hills area this dune type appears to be a modified transverse one. The sands in this dune area were apparently derived from deltaic deposits similar to the Cache Creek dune area to the south. The significance of this area arises from the fact that this is the only location in Alberta where lacadena ridge dunes constitute the main dune type.

4.6 Sand Accumulations Void of Eolian Relief

Winds and streams are among the main transporting agents of sands in Alberta. Much of the sand deposited often show eolian relief features but in certain areas sand accumulations are void of eolian relief.

Although detailed studies are needed to firmly establish the formation characteristics of these deposits, it would seem that the cause of the movement and subsequent accumulation of sand sheets is not very different from the causes of the eolian sand movement. Wind and the amount of sand present are the major factors which determine whether relief features will be present or not.

4.6.1 Sand Sheet

In Alberta, extensive sand sheets have been observed around the Caroline/Eckville area near Rocky Mountain House. These sand sheets show little relief.

Sand sheets are also evident east of the Carmangay Sand Hills in the vicinity of Lethbridge. Accumulations of loess which are deposits of fine eolian silts or dust are also common near the sand hills. In the vicinity of Magrath and Raymond, in Southern Alberta, is a large area of scattered sand sheets.

In Central and Northern Alberta, sand sheets occur near Swan Hills, Lac La Biche, and in the vicinity of Bitumont just north of Fort McMurray. Accumulations of loess also occurs imperceptibly in various locations in the Peace River district (east of Peace River, around Lubicon Lake and west of the Peace River, near Hines Creek).

GLOSSARY

deflation: The removal of material from a beach or other land surface by wind.

deposit: An accumulation of sediments left in a new location by a natural transporting agent such as water, wind, ice or gravity.

dune: In every part of the world where the surface is sandy, the sand is frequently driven about by the wind and onsequently it drifts into hillocks or heaps called dunes.

dune, barchan: Crescent-shaped hill of bare sand which moves slowly across a relatively falt nonsandy surface. The "horns" of the crescent that move in advance of the main mass of sand are always pointed with the wind.

dune, blowout: Dune generally parabolic in shape, which surrounds the deflation hollow from which the sand forming the dune has been derived. The base of the deflation always lies below the level of the surrounding area.

dune, fish hook: A sand dune which resembles, in plain view, a fish hook. Although it could be classified as an extremely asymmetrical elongate parabola dune in which one of the wings has completely disappeared, it has a short extension downwind at the base of the head.

dune, harpoon: An elongated sand ridge, generally straight, with a hook-shaped appendix located at some point along its side, resembling a harpoon. It is formed either by the development of a small parabola dune along the side of a dune ridge or by the extreme elongation of a former dune which became asymmetrical and lost most of one side, except for the part that forms the hook.

dune, longitudinal:	Sand ridge which is elongated and parallel to the principal sand-moving direction. Longitudinal dunes always occur in large numbers and form geometric patterns.
dune, parabola:	Dune whose head, wings and back ridge form a completely closed circle around the deflation depression.
dune, sand:	Sand piled by wind into dunes and composed predominantly of particles.
dune, shield:	Dune formed by relatively straight frontal slope (in plain view) with short wings curving up and continuing in a series of arcuate ridges at the back.
dune, tongue:	A narrow downwind extension of a dune area formed by a variety of dunes which migrated from the main body of the dune area.
dune, transverse:	A dune forming a wave-like ridge transverse to the prevailing wind direction.
dune, twinned:	Simplest form of composite dunes in which two dunes of the same type are attached to one another side by side.
dune, U-shaped:	A U-shaped dune with the open end of the U facing upwind. The redistributed sand in the dune has a gentler interior (upwind) and a steep exterior (downwind) slope.
dune, zigzag:	Dune formed by the joining of a series of V-shaped dunes side by side resulting in a zigzag pattern. However, each successive location on the dune ridge, where a change in the orientation of the ridge occurs, appears to represent a dune head, as if sand movement had occurred in opposing directions.
eolian:	A formation of recent origin, consisting of marine sand drifted and arranged by wind. A term applied to the erosive action of the wind, and to deposits which are caused by the transporting action of the wind.

loess:	Largely homogeneous deposits of unstratified silts, deposited primarily by wind.
morphology:	The science of the outer form and internal structure of the earth, without regard to the functions of plants and animals.
ridge, border:	An elongated sand ridge, most frequently irregular in plain view, forming at the edge of deflation areas.
ridge, dune or sand:	A generalized term to describe ridges of wind blown sand most often representing part of former dunes destroyed by deflation.
ridge, lacadena:	A relatively short and somewhat wide dune ridge having a low central axis along its centre line and having slip-face line slope along both sides.
saltation:	Sand particles leaping across the ground within a certain height above the ground.
saltation creep:	The slow and imperceptible movement of finely broken up rock matter from high or low levels.
sand hills:	Area of mounds and ridges of sand constructed by the wind or through anthropogenic activities.
wind pit and blowout hollow:	Depressions formed by deflation of sand through a breach in the vegetation cover or through some other form of surface protection (e.g. soil pan).

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APPENDIX I

SUMMARIZED DATA ON EOLIAN LANDFORMS OF ALBERTA

MIRCAH
BUSINESS
ENTERPRISES

EOLIAN LANDFORMS IN ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Wood Buffalo Sand Hills	Situated east of Caribou Mountains and extends north and south of Peace River valley. Most of the sand dunes area lies within the boundary of the Wood Buffalo National Park.	84P, 84I, 84J and 74M	59°	113° 15'	Various dune types are found. These include Parabola, which are mostly asymmetrical and/or elongate. Others are V-shaped, transverse and to a lesser extent harpoon and zigzag dunes. The form of the dunes is accentuated by the differential vegetation growing on them.
Richardson Lake Ronald Lake and Old Fort Bay Sand Hills	Lies south of Lake Athabasca and to the southeast of Lake Claire. Main dune areas lie just south of Richardson Lake and around Ronald Lake. West of the Athabasca River lies Old Fort Bay dune area, about 40 km northeast of Richardson Lake.	74L, 74E	58° 20'	111° 15'	Mostly parabola, asymmetrical and some symmetrical parabola dunes. A few V-shaped dunes and longitudinal dunes are present near Harrison River. Many of the parabola and V-shaped dunes form composite arrangements of the 'in-line' and 'en echelon' types.
Fort Vermilion and La Crete Sand Hills	Located along the northwest side of the Peace River valley, upstream from Fort Vermilion. La Crete dune area lies on the eastern side of Peace River valley approximately 3 km west of La Crete and 30 km southwest of Fort Vermilion.	84K, 84J	58° 15'	116° 50'	Mainly parabola and transverse (elongate, V-shaped) dunes present, with Lacadena type and ridges occurring in the La Crete Sand Hills. Parabola dunes are superimposed over the transverse. Hence the former dunes were the last ones to develop in the area.

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EOLIAN LANDFORMS OF ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Wolverine Sand Hills	Lies only a few kilometres north of Cache Creek Sand Hills, on the east side of the Peace River valley.	84F	57° 40'	117° 00'	Lacadena type sand ridges, which appear to be modified transverse dunes are predominant.
Cache Creek Sand Hills	Dune area is located approximately 48 km NNE of Manning, on the east side of the Peace River valley.	84F	57° 20'	116° 55'	Mainly transverse and parabola dune types with transverse dune types being most common. Some dunes are transitional in form between transverse and parabola. Transverse dunes appear to have been formed by NNW winds and parabola dunes were formed by WNW winds.
Fort McMurray Sand Hills	Located on the northern and southern sides of the Athabasca River valley. Approximately 24 km southwest of Fort McMurray.	74D, 84A	56° 40'	112° 00'	Mostly asymmetrical parabola dunes. The dunes were apparently formed by winds blowing from the east. But asymmetrical forms in the west may have been formed by gentler winds from the north and also from the south. This area has extensive bogs and swamps which have dunes sticking up through them.
Algar River Sand Hills	Situated about 75 km southwest of Fort McMurray and just west of Athabasca River.	84A	56° 25'	112° 25'	Transverse and parabola dunes are most common; some filled dunes are evident. Dunes are oriented to northwest to southeast. Dune forming winds were from the east. The dunes are covered by thick forest on the upper parts and bogs in the lower areas.

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EOLIAN LANDFORMS OF ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Wood Buffalo River Sand Hills	Lies south of Wood Buffalo river valley. Dune occurs in four small areas.	84A	56° 30'	113° 25'	Longitudinal dunes most common particularly in the NE section. Parabolic forms also present but less common. Dunes here are orientated northwest to southeast.
Watino Sand Hills	Dune area is located 6-8 km south of Watino on either side of Smoky River valley.	83N	55° 35'	117° 45'	Mostly parabola, elongate parabola and V-shaped dunes occur here. The dunes resemble those of Grande Prairie region in type and form.
High Prairie Sand Hills	Lies approximately 10 km northeast of High Prairie and approximately 20 km northwest of Lesser Slave Lake.	83N	55° 30'	116° 25'	Main dune type here is parabola, mostly open. The dune field appears to have been stabilized by vegetation growth.
1) Chisholm 2) Bruce Lake 3) Hondo and Decrene (4) Sand Hills	These dunes can be located on either side of the Athabasca River south of Fawcett Lake. Chisholm and Hondo occur on the east side of the Athabasca River while Bruce Lake and Decrene Sand Hills occur on the west side of the Athabasca River.	83P, 83O, 83I, 83J	1) 54° 50' 2) 54° 55' 3) 54° 05' 4) 55° 10'	114° 10' 114° 15' 114° 00' 114° 10'	Mainly parabola dunes. V-shaped and elongate parabola dunes are also present. Most dunes form 'in-line' and 'en echelon' type composite arrangements. All four dune fields formed on deltaic deposits. All areas are characterized by wide spread occurrences of muskeg, swamps, and open lakes.

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EOLIAN LANDFORMS OF ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Lesser Slave Lake Sand Hills	Lies to the east of the Lesser Slave Lake, a few kilometres beyond the NE outskirts of Slave Lake.	83O	55° 15'	114° 35'	V-shaped dunes are the most common here, particularly east and south of the Lesser Slave river valley. This dune field is part of a long ring-like dune formation running to the south and west through Whitecourt, Windfall, Fox Creek and Grande Prairie groups. The formation appears to have resulted from the SW winds which affected the area.
Nelson Lake Sand Hills	The dunes are situated east of the Athabasca River, between Pembina River and the Athabasca River.	83I, 83J	54° 30'	114° 15'	Dunes are all of parabola type, with elongate forms developing in the south. Higher dune density prevail in the south than in the north. Present also are some 'in-line' composite type arrangements. This is one of the largest dune occurrences in the Fort Assiniboine area. Inter dune areas consist of extensive muskeg, swamps and open lake which form a chain in the north.
Fort Assiniboine Sand Hills	Occurs north and south of the Athabasca River in the vicinity of Fort Assiniboine. The dunes here appear more reworked in the south than in the north.	83J	54° 30'	114° 30'	Preserved transverse dunes occur in the eastern parts of the northern half of the dune field. In southeastern part, dunes are transitional between transverse and parabola. Well shaped parabola dunes occur in the southwest.

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EOLIAN LANDFORMS IN ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Holmes Crossing Sand Hills	Located on the southern side of the Athabasca River just south of the settlement of Fort Assiniboine.	83J	54° 20'	114° 30'	Dunes here are of transverse form. Also present are the parabola dunes, mostly asymmetrical. The transverse type dunes are often encircled by the parabola dunes in the area. This dune area is unique in Canada, particularly as far as stabilized transverse dunes are concerned. Some of these dunes appear as embrionic barchan in plain view. Unlike at any other location in Alberta, these dunes are so well reserved and well preserved here.
Fish Lake Sand Hills	Dune area is located on the northern side of the Athabasca River valley between Whitecourt sand hills and Holmes Crossing sand hills.	83J	54° 10'	115° 15'	The main occurrence here are parabola dunes with some elongate forms, that have a higher density of population than Whitecourt sand hills. The dunes in this field were developed on a sandy delta.
Whitecourt Sand Hills	Situated about 15 km SW of Fish Lake sand hills, a few km SE of Whitecourt. The main dune area lies south of the Athabasca River. Smaller occurrences lie north of the river valley.	83J	54° 10'	115° 35'	Mainly elongate parabola dunes are found here. The dune density is low. These dunes are developed on sandy deltaic deposits.

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EOLIAN LANDFORMS IN ALBERTA

EOLIAN LANDFORMS	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Bear River Sand Hills	Lies just north of Wapiti River, approximately 6 km east of Grande Prairie.	83M	55° 10'	118° 40'	Dunes here are of the open parabola type, fairly dense in numbers. Also present are some asymmetrical parabola dunes as well as 'en echelon' composite forms.
Wapiti River and Pipestone Creek Sand Hills	Situated approximately 3 km north of the hamlet of Wapiti, south of the Wapiti river valley. The Pipestone Creek sand hills are located on the north side of the Wapiti River and approximately 15 km SW of Grande Prairie.	83M, 83L	55° 00'	119° 10'	Mainly elongate parabola dunes are found here. The dunes can be several km long in some areas. In many parts, however, thick bog cover make the dunes hard to discern.
Ellenwood Lake Sand Hills	The dune area is located southeast of Smoky River. Approximately 32 km southeast of Grande Prairie.	83L	54° 55'	118° 20'	Open parabola type dunes are fairly common here. In addition, elongate forms are also present. This field is the largest continuous dune occurrence in Grande Prairie Group. There are bogs in this dune field.
Economy Creek Sand Hills	Situated west and south of Simonette River, and east of the valley of Economy Creek.	83M	55° 05'	118° 10'	Elongate parabola in certain areas, however, the dunes are transitional between elongate and parabola. Smaller in size than in other dune areas. Eastward extending lobes in the eastern boundary reveal local effects of past dune migration.

MICAH BUSINESS ENTERPRISES

EOLIAN LANDFORMS OF ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Pinto Creek Sand Hills	Situated south of the Wapiti River valley, about 40 km southwest of Grande Prairie.	83L	54° 55'	119° 20'	The main dune types found here are elongate, narrow parabola dunes and V-shaped dunes. Extensive bogs cover the area and lower parts of the dunes. Upper parts of the ridges stick up through the bog.
Grovedale Sand Hills	Lies on the south side of Wapiti River directly south of the Bear River sand hills. The hamlet of Grovedale occurs in the midst of these sand hills.	83M, 83L	55° 00'	188° 45'	Mostly elongate parabola type of dunes are found here. The interdune areas are covered by bogs.
Brazeau Sand Hills	Lies between Pembina River and Brazeau River, just northwest of the Brazeau Dam.	83G, 83B	53° 05'	115° 50'	Mainly longitudinal type dunes do occur aligned in a NE/SE direction.
Rocky Mountain House Sand Hills	Located around Rocky Mountain House and also at about 40 km north and 20 km east of Rocky Mountain House.	83B	52° 30'	115° 00'	Elongate parabola dunes recognizable here. Dunes occur in small scattered areas.

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EOLIAN LANDFORMS IN ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Windfall Sand Hills	Lies to the west of Whitecourt sand hills. The main occurrence lies south of Athabasca River with a smaller dune area to the north of the river valley.	83K, 83J	54° 10' to 54° 15'	115° 55' to 116° 25'	Dunes are found in 4 areas. All the dunes here are classified as the parabola type. Two dune areas to the west have low density elongate dunes. In the eastern part the dunes are the parabola type but elongate and V-shaped dunes are also common. In the centre the dunes are short and are grouped into an 'in-line' composite arrangement.
Edson Sand Hills	Situated about 5 km south of Edson, almost due west of Edmonton.	83F	53° 30'	116° 30'	The dunes found here are the parabola type. In the western part the dunes are filled and have short wings. In the eastern part the dunes are mostly open. Dense vegetation growth has stabilized the dunes. Extensive areas of bog, swamps and open lakes occur particularly in the west.
Eastgate Sand Hills	The dune area is located about 32 km northeast of Edmonton.	83H, 83I	53° 55'	113° 15'	Dune field consists of parabola dunes which are partly elongate. Often occur in 'in-line' and 'in-succession' composite forms.
Stony Plain Sand Hills	Dune area lies just west and southwest of the Stony Plain Indian Reserve, southwest of Edmonton.	83H	53° 30'	113° 50'	Mainly parabola dunes are found here. Minor occurrences of elongate forms have also been identified in the area.

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EOLIAN LANDFORMS OF ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Kilsyth Lake Sand Hills	The dune area is located about 50 km NE of the hamlet of Westlock and about 30 km SW of Athabasca on the eastern side of Pembina River valley.	83I	54° 35'	114° 05'	Parabola constitute the main dune type. The dunes are also somewhat elongate in NW-SE south. Many of the dunes form an 'in-line' type composit arrangement. The morphology of the dunes reflects shallow source deposits reworked by aeolian activity of long duration.
Westlock Sand Hills	Dune field is located to the north of Edmonton (approximately 50 km) east of Westlock; north and east of junction to both Edmonton and Athabasca.	83I	54° 10'	113° 35'	Identifiable features here include blow out dunes and blow out hollows. Sand dunes here are, morphologically, poorly developed.
Redwater River Sand Hills	Lies about 60 km northeast of Edmonton. Dune area lies north of North Saskatchewan River valley near the town of Redwater.	83H	53° 50' to 53° 55'	113° 00' to 112° 30'	Parabola dunes are common here. The dunes are relatively small and poorly developed except in the area west of the town of Redwater. Some dunes form composite arrangement. The interdune areas are covered either by eolian sands or wetlands.
Beaverhill Creek and Ukalta Sand Hills	Located about 32 km north east of Edmonton also south and southeast of the North Saskatchewan River.	83H	53° 50' to 53° 55'	113° 00' to 112° 30'	Parabola dunes, essentially same as above.

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EOLIAN LANDFORMS OF ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Sounding Lake Sand Hills	Occurs within 20 km northwest to southwest of Provost.	73D	52° 20'	110° 35'	Blow out dunes and blow out hollows constitute the main dune types in this area.
Edgerton Sand Hills	Located between Wainwright and the Alberta-Saskatchewan border.	73D	52° 40'	110° 20'	This dune field is characterized by sand ridges (North Battleford type) with small shallow, blow out depressions.
Middle Sand Hills	Most of the dunes are located along the western side of the south Saskatchewan River. The dune areas are situated about 50 km northeast of Medicine Hat and extend north for about 40 km.	72L	50° 40'	110° 20'	Various dune types are found here. The major ones are elongate parabola dunes, but also common are shield and blow out forms. This dune field consists of one major occurrence in the south, one smaller occurrence and three clusters of small dune occurrences to the northeast. Regionally this is an important dune field. It also covers a large area.
Hilda Sand Hills	Lies east of the main Middle sand hills, just east of south Saskatchewan River.	72L	50° 35'	110° 05'	The major occurrence here are parabola dunes with minor elongate forms, blow out hollows and blow out dunes border these sand hills.
Carmangay Sand Hills	Lies north and south of the Bow River between Champion and Nobleford , Alberta.	82I, 82H	50° 05'	113° 05'	Various types of dunes occur here. Mostly longitudinal dunes with frequent occurrences of blow out dunes and blow out hollows.

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EOLIAN LANDFORMS IN ALBERTA

EOLIAN LANDFORM	LOCATION	1:250 000 NTS MAP SHEET	LAT. °N	LONG. °W	DESCRIPTION
Grassy Lake Sand Hills	Situated on the south side of Oldman River near the junction of the Oldman and the Bow Rivers.	72E	49° 50'	111° 50'	Major dune types found here are blow out dunes, blow out hollows and elongate parabola dunes. In areas within the dune field 'in-line' composite forms have been observed.
Pakowki Lake Sand Hills	Lies northwest of Pakowki Lake about 8 km west of Manyberries.	72E	49° 25'	110° 55'	Important dune types here include elongate parabola dunes with extensive occurrences of blow out hollows and dunes. Compared to Grassy Lake, Pakowki dunes are shorter, less well developed and show fewer composite forms.
Milk River Sand Hills	Located to the south and southwest of Milk River valley, about 11 km from Alberta/U.S. border.	82H	49° 05'	112° 10'	Blow out sand dunes and blow out hollows are common here.
Bowmanton Sand Hills	Situated about 24 km north and northeast of Medicine Hat, near the settlement of Bowmanton.	72L	50° 15'	110° 35'	Parabola dunes occur together with other transitional forms eg. V-shaped and elongate parabola dunes. Area is composed of four separate dune fields.

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